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# Development of building materials embodied greenhouse gases assessment criteria and system (BEGAS) in the newly revised Korea Green Building Certification System (G-SEED)

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ABSTRACT

This study aims to develop a Building materials Embodied GHG Assessment Criteria and System (BEGAS) in the newly revised Korea Green Building Certification System (G-SEED). For this purpose, green building certification systems and supporting assessment systems were analyzed in order to grasp the current trend of the GHG emission assessment on building materials. The evaluands were selected by identifying the major building materials in the GHG emission assessment that meet the cut-off level of ISO 14040 for GHG emission assessment. In addition, standard quantity of GHG emissions were calculated for the G-SEED and BEGAS. An auto quantity input technique was presented using pure resource code, composed of standard work codes of the Public Procurement Service (PPS), as a medium, in order to support the easy assessment of GHG emission. Korea LCI DB, the Korean DB of environmental information on building materials, and the Korea carbon footprint labeling certificate were adopted to the database for analyzing the social features of Korea. As a result, based on the aforementioned database, the criteria of GHG emission assessment for building materials in Korea's G-SEED were proposed, and a web-based BEGAS was developed.



**Contents**



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## 1. Introduction

Internationally, greenhouse gases (GHGs) are arguably the most prevalent global environmental problem. According to International Energy Agency (IEA), buildings account for almost 30% of GHG emissions [1–4]. Accordingly, much effort has focused on reducing GHG emissions in the building industry over the last few decades [2,3,5,6]. As a part of this effort, environmentally advanced countries, such as the USA, the UK, and Japan, have competitively created a set of criteria for evaluating GHG emissions of building materials using a green building certification system [7]. Leadership in Energy and Environmental Design (LEED), green building certification system in US, has improved assessment criteria of building materials' GHG emissions since the building life cycle assessment (LCA) criteria was first reflected in 2009 [8–11]. Building Research Establishment Environmental Assessment Method (BREEAM) in the UK also promote consistently GHG emissions assessment of building materials since it was newly revised in 2009 [9–12]. Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan has evaluated the GHG emissions of building materials using the $CO_2$ emission database of major materials since 2010 [7,9,11,13]. Since then many different green building certification systems are currently in preparation to evaluate GHG emissions of building materials.

Due to the large amount of data required to perform GHG emissions assessment on building materials, it is recommended to use an assessment system that makes the assessment much more efficient [14]. In this regard, government and private research institutions have critiqued this GHG emissions assessment system for building materials, which is capable of supporting green building certification systems [15]. For instance, Athena EcoCalculator is to support LEED and Green Globes to evaluate the GHG emission of the building materials [8,16]. Envest2 and IMPACT also supports the assessment criteria of building life cycle impacts that are applied in the BREEAM [12]. However, it is important to choice of suitable assessment system depends on the purpose of assessment, regional environment, location, database and system boundary. Rossi at al. pointed out a difference of the GHG emissions result depends on location [17]. Bribián et al.'s study found that too many existing assessment systems display different result [14]. Dixit et al. have pointed out a difference of result in accordance with system boundary [3].

Meanwhile, according to the Korea Energy Economics Institute, Korea is the 9th biggest country of GHG emission in the world [18]. Therefore, Korea has gradually implemented and expanded upon the building a control system for GHG and energy goals [19,20]. However, the current GHG reduction policy focuses on the energy consumed in the operation process of building, which therefore limits its breadth as it fails to consider the GHG emissions of the building materials, which comprise approximately 32% of the GHG emissions in a building's life cycle [21–23]. Thus, in early 2013, Korea changed the green building certification criteria (GBCC) to recognize a Green Standard for Energy and Environmental Design (G-SEED). With a reorganization of certification items in June 2013, criteria have been created to determine a GHG emission assessment for building materials, in order to meet international agendas [24]. However, there are no sufficient studies that develop the criteria and system for evaluating GHG emissions of building materials in light of G-SEED.

This study aims to develop a Building materials Embodied GHG Assessment Criteria and System (BEGAS) in the newly revised Korea Green Building Certification System (G-SEED).

With that aim, green building certification systems and supporting assessment systems were analyzed in order to grasp the current trend of the GHG emission assessment on building materials. The evaluands for GHG emission assessment were selected by identifying the major building materials in the GHG emission assessment that meet the cut-off level of ISO 14040 [25], based on the bills of quantities of actual apartment houses and office buildings. In addition, standard quantity of GHG emissions were calculated for the G-SEED and BEGAS. An auto quantity input technique was presented using pure a resource code, composed of standard work codes of the Public Procurement Service (PPS) [26], as a medium, in order to support the easy assessment of GHG emission. Korea LCI DB [27], the Korean DB of environmental information on building materials [28], and the Korea carbon footprint labeling certificate [29] were adopted to the database for analyzing the social features of Korea. Based on the aforementioned database, the criteria of GHG emission assessment for building materials in Korea's G-SEED was proposed, and a web-based BEGAS were developed. Fig. 1 shows the framework and process of this study.

## 2. Literature review

Many of the green building certification systems, a lot have been about the review of individual green building certification system and the comparison of LEED or BREEAM with another certification system [30–34]. However, no existing literature can be found in respect to the review of a relationship between the green building certification system and GHG assessment system.

In this regard, the ultimate goal of this chapter is to derive a relationship between the green building certification system and GHG assessment system through the review of building materials GHG assessment criteria. Accordingly, the GHG assessment criteria were analyzed relevant to building materials that are most commonly used in green building certification systems throughout the world, including: LEED (US), BREEAM (UK), CASBEE (Japan), Green Globes (Canada) and Korean G-SEED (before amendment). In addition, some of the above green building certification systems were analyzed by reflecting methods of the building materials GHG assessment. Table 1 shows the comparison of building materials GHG assessment criteria in the green building certification systems.

### *2.1. Analysis of building materials GHG assessment criteria*

#### *2.1.1. LEED v4*

US LEED is carried out in the categories of: housing, housing complexes, commercial interiors, lease buildings, general new

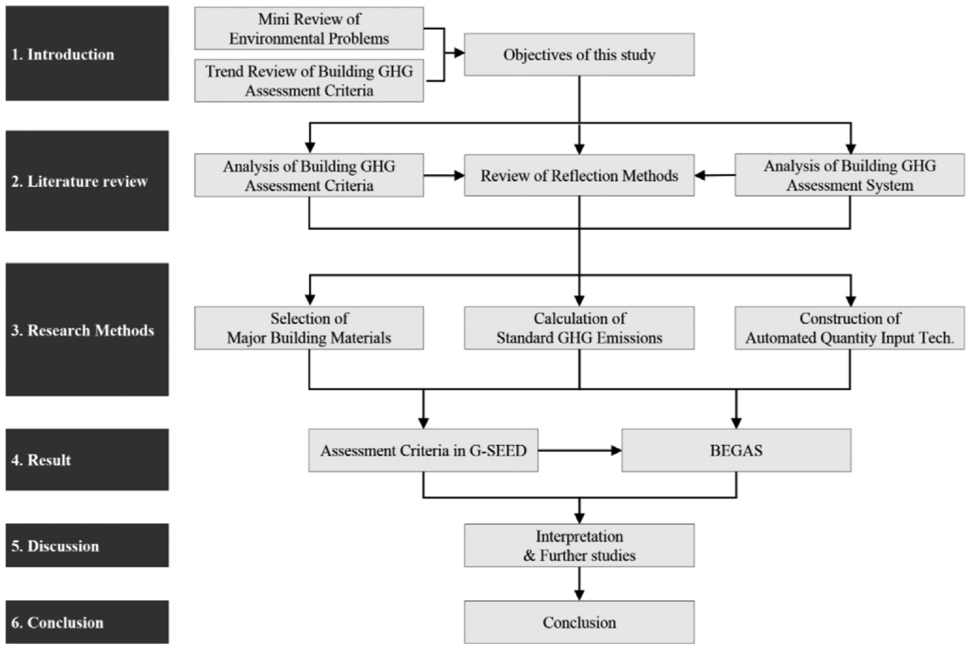



**Fig. 1.** Framework and process of this study.

**Table 1**
Comparison of green building certification system.

| Classification | LEED v4 | BREEAM 2009 | CASBEE 2010 | Green Globes | G-SEED (before amendment) |
|---|---|---|---|---|---|
| Country | USA | UK | Japan | Canada | Korea |
| Year Announced | 2012 | 2011 | 2010 | 2010 | 2011 |
| Target | New buildings | New buildings | New buildings | New buildings | All buildings |
| By | USGBC | BRE | Japanese Ministry of Land, Infrastructure, Transport and Tourism | Athena Institute | Korea Ministry of Environment<br>& Korea Ministry of Land, Infrastructure and Transport |
| Evaluation item classification system | Sectors (7) | Sectors (10) | Sectors (2) | Sectors (7) | Sectors (9) |
| | Evaluation items (56) | Evaluation items (50) | Evaluation items (55) | Evaluation items (16) | Evaluation items (52) |
| Building materials LCA evaluation item | Materials and Resources | Materials | Resources and Materials | Resources | – |
| Environment impact evaluation items | GWP, ODP, AP, EP, POCP, ERS | 7 in addition to AD, OD, HTox Water, HTox Air, POCP, Ecotox | $LCCO_2$ | GWP, ODP, AP, EP, POCP, ERS | – |
| Building materials LCA evaluation method | LEED LCA Credit Calculator evaluation based on EcoCalculator | Green Guide to Specification evaluation based on Green Guide | Self-evaluation through spread sheet | GHG evaluation based on EcoCalculator | – |
| Building materials LCA score | Up to 3 points | Up to 5 points | BEE index | Up to 35 points | – |
| Total score | 100 Points<br>+4 Points (Regional Prop.)<br>+6 Points (Innovation Design) | Convert to 100% based on 112 points | Convert the building environment efficiency index (BEE) | Convert to 100% based on 1000 points | 145 points |
| Certification grade | 1. Platinum (80–100 pts)<br>2. Silver (60–79 pts)<br>3. Gold (50–59 pts)<br>4. Certified (40–49 pts) | 1. Outstanding (85%)<br>2. Excellent (70%)<br>3. Very Good (55%)<br>4. Good (45%)<br>5. Pass (30%) | S, A, B+, B−, C (indicate graph) | 1. 4 Globes (85%)<br>2. 3 Globes (70%)<br>3. 2 Globes (55%)<br>4. 1 Globes (35%) | 1. Best ( > 74 pts)<br>2. Excellent ( > 66 pts)<br>3. Good ( > 58 pts)<br>4. Ordinary ( > 50 pts) |

buildings (big repairs), schools, commercial buildings and hospitals [7]. The items of assessment can be applied in the design, execution and operation stages, according to the buildings' features [8,10,35,36]. Of these, an assessment criterion of the building materials' GHG emissions was included in the Materials and Resources section. When this section was established (LEED

v4, 2012) as the No. 1 assessment item (M.R. Credit 1. Building life-cycle impact reduction) in the materials and resource part with extra point (LEED v3, 2009) from the existing innovation design criteria, it added weight to the influence of GHG emission assessments for the building materials in the certification system [37]. The GHG emissions of building materials can be evaluated using Option 4. A whole-building life-cycle assessment of M.R. Credit 1 determined that up to 3 points would be given. In particular, this assessment item includes the global warming potential (GWP) using the LCA system designated at LEED, including an Athena EcoCalculator for assemblies and BEES, and it also rates the given scores when there is reduction effect over 10% compared to reference buildings by evaluating 3 or more environmental factors, including: acidification potential (AP), ozone depletion potential (ODP), photochemical ozone formation potential (POCP) [8,37].

#### 2.1.2. BREEAM

UK BREEAM is separated into categories for new buildings, reconstructions, residential complexes and maintenance areas and applies assessment standards to each building feature [10,12,38]. In particular, the GHG emission assessment items for building materials corresponds to the materials parts, and the LCA of buildings is conducted using Mat.1: Life cycle impacts (major building elements) certification items, among 7 assessment items [12,39]. The evaluands are the main sections of each of the building types and are separated into methods of applying a green guide database, which is a database on the environmental effect of building materials constructed at BRE, and that of utilizing LCA system designated at BRE. With regard to the assessment method of the green guide database, grade assessments are conducted using a summary rating for each of the 290 major building elements, which were compiled with a total of 13 environmental effect assessment factors and GHG emissions [12]. Four points were given. At this time, when the maximum score is exceeded, an additional 1 point is given for the innovation design criteria. Conversely, for an assessment method using a LCA system, Envest2 (or IMPACT, Eco-Quantum) should be used, which can evaluate more than 3 environmental impact factors while satisfying the ISO assessment standard. This method can give up to 5 points if there is documented evidence proving the confirmation of an environmental load reduction of materials compared to reference buildings.

#### 2.1.3. CASBEE

Japan's CASBEE is an assessment system in which the index separates the building's environment efficiency (BEE) into the numerator of BEE, Q (Quality: building quality performance, users' life comfort requirements in a virtual closed space) and denominator L (Loadings: external environmental performance, including virtual closed space and external environmental load of building) [9,11,13]. It consists of Q1 (interior environment), Q2 (service performance), Q3 (external environment outside lots), L1 (energy), L2 (resource and materials) and L3 (environment outside lots). The GHG emission of the building materials is evaluated at L2 (resource and materials). In particular, the life cycle $CO_2$ emissions of buildings is evaluated using the L2.2.2 (Continuing Use of Existing Structural Frame) criterion. The materials used for the assessment are: concrete, blast-furnace cement concrete, sectional bar, rebar and wood. CASBEE does not use an external system, but evaluates the life cycle of the buildings' $CO_2$ emissions using the direct input in a spreadsheet (Microsoft Excel$^{TM}$). This system uses a $CO_2$ database of materials input per unit area according to the use and structural form of the building [40–42].

#### 2.1.4. Green globes

Canada's Green Globes is the certification system that evaluates new construction, existing building, and healthcare. It evaluates the energy, water, resources, load, internal environment and project management, with total score of 1000 in a conversion to 100% [16]. Among these, a criterion for a GHG impact assessment of the building materials was included in the resources, building materials and solid waste. Up to 35 points are given, according to the execution of the LCA of 4 main members: foundation and flooring materials; structures, such as pillars and walls; roofing materials; and combinations of other materials, using an ecocalculator for assemblies in Section 5. (Systems and materials with low environmental impact).

#### 2.1.5. G-SEED (before amendment)

Korea's G-SEED (before amendment) is classified into nine categories: as land use, transportation, energy, materials, resources, water resources, prevention of environmental pollution, maintenance, ecosystem and interior environment [43]. The total scores are calculated with weighted values and achievement rates for each of the 50 criteria. Assessments are conducted on all types of buildings, with different criteria for new buildings versus remodeled ones; however, the assessment criteria of GHG emissions of construction materials have not yet been established [44,45].

### 2.2. Analysis of building materials GHG assessment system

#### 2.2.1. Athena EcoCalculator for assemblies

Athena EcoCalculator is a spreadsheet-based LCA tool developed by the ATHENA Institute in association with the University of Minnesota and Morrison Hershfield Consulting Engineers. Architects, engineers and other design professionals can have instant access to instant LCA results for hundreds of common building assemblies using the Athena EcoCalculator for assemblies [46,47]. The tool was commissioned by the Green Building Initiative (GBI) for use with the Green Globes environmental certification system. The system boundary of this system includes material extraction and manufacturing, related transport, on-site construction of assemblies, maintenance and replacement, demolition, and transport to landfill. It can evaluate GHG emission, embodied primary energy, pollution to air, pollution to water, weighted resource use using the ATHENA database (cradle-to-grave) and US LCI Database [48]. According to AIA guide to LCA of buildings, Athena EcoCalculator has some strengths and weaknesses. This system makes it easy to obtain the environmental impact result in real time and compare different assemblies. However, it is only available in custom assembly options. Column and beam sizes are fixed [46].

#### 2.2.2. Envest 2

Envest 2, developed by BRE of the UK, is a web based system that simplifies the complex process of designing buildings with low environmental impact and whole life costs [49,50]. It is mainly intended for analyses of office buildings. The system boundary of this system includes material extraction and manufacturing, related transport, on-site construction of assemblies, operation, maintenance and replacement, and demolition. It can evaluate GHG emissions, acid deposition, ozone depletion, eutrophication, human toxicity, eco toxicity, waste disposal, etc [51]. The assessment and results of this system are expressed as Eco Point, the unique indicator of ENVEST. In general, 1 Eco Point is equivalent to the same amount of GHG in water resource of 1.38 $m^3$.

### 2.2.3. IMPACT

IMPACT, Integrated Material Profile and Costing Tool, allows construction professionals to measure the embodied environmental impact and life cycle cost performance of buildings. Its compliant system works by allowing the user to attribute environmental and cost information to drawn or scheduled items in the Building Information Modeling (BIM) [52]. IMPACT classifies life cycle impact of building materials into a construction/installation stage, a maintenance stage, and a dissolution/re-use/disposal stage, and calculates the embodied environmental impact and life cycle cost for each stage. The feature of this system is that it can analyze the design to optimize cost and environmental impacts, and compare whole-building results with a suitable benchmark to assess performance, which can be linked to building assessment schemes [53].

## 2.3. Review of reflection methods of the building materials GHG assessment

Based on the aforementioned analysis, relationship between the green building certification system and building materials GHG assessment systems were analyzed to discuss application methods. As a result, existing certification systems showed difference in the scope of recommended system and assessment according to the certification criteria. For example, IMPACT that implements BIM was recommended for BREEAM 2013 [12], while the use of Athena EcoCalculator for assemblies was recommended for Green Globes [16]. This suggests that the conditions and levels of construction industry were preferentially considered in reflecting GHG emission of building materials on the certification systems. In addition, in order to reflect regional environment of nations, it is recommended to use the assessment systems developed by the nation in which the certification system is implemented. Moreover, as a result of analyzing the scope and subjects of assessment on the green building certification systems, assessment scope of LEED included life cycle of buildings except for the stage of use [8]. Six environmental impact categories including GHG emission were the subjects of assessment. Assessment scope of BREEAM is life cycle of buildings including the stage of use, and scores are granted differently according to the scope of assessment. Further, 13 environmental impacts including GHG are applied as the evaluand [12]. On one hand, CASBEE has life cycle of buildings as the assessment scope and only uses GHG emission as the evaluand [13]. The scope of environmental impacts regarded as important differs according to the nation that implements the certification system. However, assessment on GHG emission was essentially reflected in all nations according to the global trend. In addition, GHG emission was generally assessed in the green building certification systems using GHG assessment system specified in the certification criteria. Score (or grade) was granted based on the scope of GHG reduction compared to GHG emission of the standard building used as reference.

The level of application of GHG assessment in the certification systems was classified into three types through the analyses described above. In other words, during stage 1 of G-SEED in Korea that applies assessment of building materials GHG emission to the certification systems for the first time, only the production stage of building materials can be configured as the scope of assessment with GHG emission as the only evaluand. As the use of buildings is considered as an important item in all existing certification systems, assessment on the production stage of building materials, which takes up over 30% of total GHG emission in the life cycle of buildings, can greatly contribute to reduction of GHG emission. Also, assessment criteria can only take into account performance of assessment on GHG emission, as in Green Globes of Canada. Scores can be granted differently based on comparison with GHG emission of the standard building. In stage 2, life cycle of buildings except for the stage of use can be assessed on 6 major environmental impacts, as similar to the method applied in LEED of the US. Assessment criteria can grant different scores according to reduction compared to specialization of environmental impact of the standard building with the same purpose, region, and size. In stage 3, life cycle of buildings including the stage of use can be assessed on more than 6 environmental impacts, as for BREEAM of

**Table 2**
Analysis of major building materials emitting GHG.

| Division | | Apartment house | | | | Office building | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Apartment house A | Apartment house B | Apartment house C | Main building materials | Government office building A | B Tower | Multipurpose building C | Main building materials |
| Floor area ($m^2$) | | 122,638 | 355,075 | 211,074 | – | 75,612 | 141,552 | 100,666 | – |
| Structure | | RC structure | RC structure | RC structure | – | SRC+RC | SRC+S structure | SRC structure | – |
| D B | | National LCI DB | Inter-Output analysis | LCI+inter-industry | National LCI DB | National LCI DB | LCI+inter-industry | Inter-Output analysis | National LCI DB |
| Cutoff Criteria | | 95% | 90% | 95% | 95% | 95% | 90% | 95% | 95% |
| Main building materials | 1 | | Ready-mixed concrete | Rebar | Ready-mixed concrete | Ready-mixed concrete | Ready-mixed concrete | Ready-mixed concrete | Rebar |
| | 2 | | Rebar | Ready-mixed concrete | Rebar | Rebar | Sectional bar | Steel | Section steel |
| | 3 | | Sectional bar | Aluminum | Insulator | Sectional bar[a] | Glass | Rebar | Ready-mixed concrete |
| | 4 | | Paint | Plywood | Cement | Paint | Rebar | Cement | Concrete Product |
| | 5 | | Glass | Concrete Product | Sand | Glass | Paint | Pipes | Glass |
| | 6 | | Concrete Product | Industrial Plastics | Paint | Concrete Product[b] | Insulator | Piping | Wood |
| | 7 | | Insulator | Paint | Concrete Product | Insulator | Cement | Valves | Clay for construction |
| | 8 | | Aluminum | Industrial metal | Aluminum | – | Concrete Product | Temporary steel resource | Stone |
| | 9 | | Cement | Synthetic resin | Stone | – | Aluminum | Glass and mirror | – |
| | 10 | | – | Glass | Glass | – | – | – | – |

[a] Steel frame: except sectional bar in RC structure.
[b] Concrete Product: concrete product including cement.

the UK. In addition, according to the latest trend of construction design drawings which is changing from CAD method only supporting 2D information to BIM method which includes diverse information about buildings, programs that can be linked with BIM (ex. IMPACT) can be applied.

## 3. Research methods

The aim of this chapter is to construct the technology and DB required by the GHG assessment criteria and system of G-SEED in Korea based on stage 1 of the three stages proposed in the previous chapter. During stage 1 of application level, only the production stage of building materials is assessed for GHG emission of building materials. Since more than 3000 building materials are used in buildings, it is necessary to deduce major building materials from the perspective of GHG emission. In addition, GHG emission of the standard building used as the reference for granting scores on the certification criteria is demanded. A technique was deemed necessary to easily select and assess major building materials emitting GHG among numerous building materials. Accordingly, DB and techniques for selection of major building materials, analysis of standard GHG emission, and quantity auto input were developed for embodiment of stage 1.

First, to identify the major building materials emitting GHG, the bills of quantities of many apartment houses and office buildings in Korea were analyzed the main building materials contributing to GHG emissions, according to the cut-off level specified in ISO 14040 [25]. Furthermore, by taking into account the opinions of a technical committee of G-SEED, a total of 4 evaluands were selected, including: ready-mixed concrete, rebar, sectional bar and cement. Second, to establish the standard GHG emission of the building materials used in apartment house that were applied in terms of the certification criteria and BEGAS, the bills of quantities of 60 types of apartment houses constructed in Korea were analyzed the amount of ready-mixed concrete, rebar, sectional bar, and cement used per unit area according to completion year, region, structural type and total floor area, and calculated the standard value of the GHG emissions generated per unit area. Lastly, for embodiment of the quantity auto input technique, standard work codes of the Korea Public Procurement Service (PPS) [26] were investigated. Standard names and specifications of building materials defined by PPS were analyzed for major building materials. In addition, auto input technique for the bills of quantities was developed using pure resource code of standard work codes through establishment of DB for major building materials.

### 3.1. Selection of major building materials

To identify the main building materials that emit GHGs, the GHG emissions of building materials used for construction were evaluated based on the bills of quantities of various apartment and office buildings (Table 2), as shown in Table 3 and Fig. 2, and identified the building materials with over 90% accumulated GHG emissions, according to the cut-off level of ISO 14040 [25]. The top six GHGs ($CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$), including $CO_2$ emissions, were set as the gases for assessment and converted them into a carbon dioxide equivalent ($CO_{2eq}$) by applying the global warming potential (GWP) of the IPCC [54]. As a result, GHG emissions of apartment houses were the highest in the order of ready-mixed concrete, rebar, sectional bars, paint, glass, concrete products, insulator, aluminum, cement. The GHG emissions of office building were the highest in the order of ready-mixed concrete, sectional bars, glass, rebar, paint, polyester (insulator), cement, concrete

**Table 3**
Result of GHG emissions assessment.

| No. | Apartment house A | | | Government office building A | | |
|---|---|---|---|---|---|---|
| | Group | $CO_2$ emissions (kg-$CO_{2eq}$/$m^2$) | Percentage (%) | Group | $CO_2$ emissions (kg-$CO_{2eq}$/$m^2$) | Percentage (%) |
| 1 | Ready-mixed concrete | 319.30 | 66.58 | Ready-mixed concrete | 262.50 | 52.73 |
| 2 | Rebar | 65.91 | 13.74 | Sectional bar | 102.75 | 20.64 |
| 3 | Sectional bar | 23.47 | 4.89 | Glass | 41.85 | 8.41 |
| 4 | Paint | 16.25 | 3.39 | Rebar | 31.94 | 6.42 |
| 5 | Glass | 11.26 | 2.35 | Paint | 20.22 | 4.06 |
| 6 | Concrete product | 10.68 | 2.23 | Insulation | 10.27 | 2.06 |
| 7 | Insulation | 8.28 | 1.73 | Cement | 8.46 | 1.70 |
| 8 | Aluminum | 7.99 | 1.67 | Concrete product | 6.34 | 1.27 |
| 9 | Cement | 7.51 | 1.57 | Aluminum | 6.29 | 1.26 |
| 10 | Other materials | 8.92 | 1.86 | Other materials | 7.16 | 1.44 |
| Total | – | 479.57 | 100.00 | – | 497.78 | 100.00 |

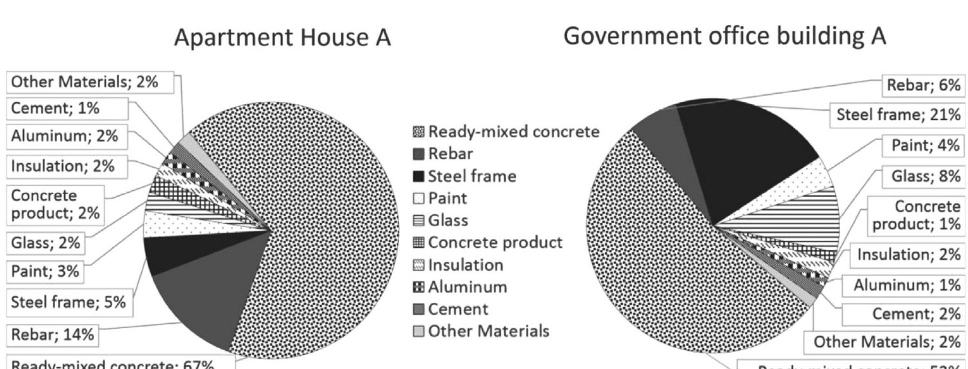



**Fig. 2.** Results of the GHG emissions assessment.

products, aluminum etc, showing a trend similar to that seen for apartments.

As a result, 7 building materials, ready-mixed concrete, rebar, sectional bar, paint, glass, concrete products and insulators, were found to comprise 90% of the GHG emissions in the apartment houses and office buildings. In this regard, this study identified the aforementioned 7 building materials and a total of 7 main building materials, including cement, which has a relatively high basic unit of GHG emission. In the case of RC structures, 6 building materials (all of the aforementioned except for sectional bar) were selected as the main GHG emission materials.

Furthermore, the material and resource subcommittee of the G-SEED technical committee consulted 7 main building materials that emit GHG (ready-mixed concrete, rebar, sectional bars, paint, glass, concrete products and insulation materials) to review the suitability and to determine the applicability of the evaluand. In addition, in consideration of the efficiency and reality of building drawings calculated according to the G-SEED assessment period during the project stage (project approval stage: preliminary certification, completion stage: certification) (Table 4), this study restricted the evaluands of the building materials for assessment to 4 types: ready-mixed concrete, rebar, sectional bars (only if the structure is an SRC or S), and cement.

### 3.2. Analysis of the standard GHG emission about major building materials

The apartment was classified according to completion year and region through 2009 using KBC 2005, and apartments after 2010 were amended with KBC 2009 in consideration of the fact that regulations on earthquake-resistance design and structural calculations may differ depending on the region and year of amendment according to Korean building codes (KBC) [55].

As a result, the GHG emission error per unit area of building materials according to the year of completion was found to be about 3%, showing similar results to the average value. Reinforced concrete structures, which are generally applied to apartment houses, were separated into reinforced concrete structures (ground floor) and steel frame reinforced concrete structures (underground floor). As a result, the error of GHG emissions of apartment houses where a steel frame was used and the apartment houses in reinforced concrete structures was found to be a maximum of 1.52%, showing similar results to the average values. Conversely, according to the classification per total floor area, the input of building materials and GHG emissions were analyzed after setting the total floor area to each 100,000 $m^2$. As a result, the GHG emissions errors per unit area of building materials was found to be about 2.8%, showing results similar to the total average value. In this regard, this study established an average value for 60 types of apartment houses when setting the input of building materials per unit area of standard apartment house, and set the GHG emission as the standard value of certification criteria and BEGAS. Table 6 and Fig. 3 show the analysis results of the GHG emission and input quantity by the various conditions.

### 3.3. Construction of an automated quantity input technique of building materials

An automated quantity input technique enters the quantities of building materials in order to assess the bills of quantities automatically with the coding of the building materials. It can solve the difficulty of quantity input and troubles due to long assessment time, which have been highlighted as weaknesses of the existing manual input type of building materials [56,57]. That is, the existing method requires lots of time and effort to collect the building materials for assessment, scattered per discipline of works in the bills of quantities, to unify the unit, to collect the materials and directly enter them in the system for a LCA. Conversely, an automated quantity input technique is efficient, as it can be evaluated using uploads after editing the bills of quantity according to the input format designated. Therefore, this study examined the standardized name and specification of building materials commonly used in bills of quantities for the standard work code of PPS [26], classified building materials (ready-mixed concrete, rebar, steel frame, cement) for assessment according to pure resource code, and further established a database of BEGAS. Table 5 shows the example of standard work code of building materials for evaluation.

**Table 4**
Evaluation period of G-SEED.

| Construction process | Basic design | Deliberation | Approval | Working drawing | Commencement and execution | Completion |
|---|---|---|---|---|---|---|
| G-SEED certification period | – | – | Preliminary certification | – | – | Certification |
| Drawings | Layout, plane | | Construction drawing | Bills of quantities | Work log | Details of completion |

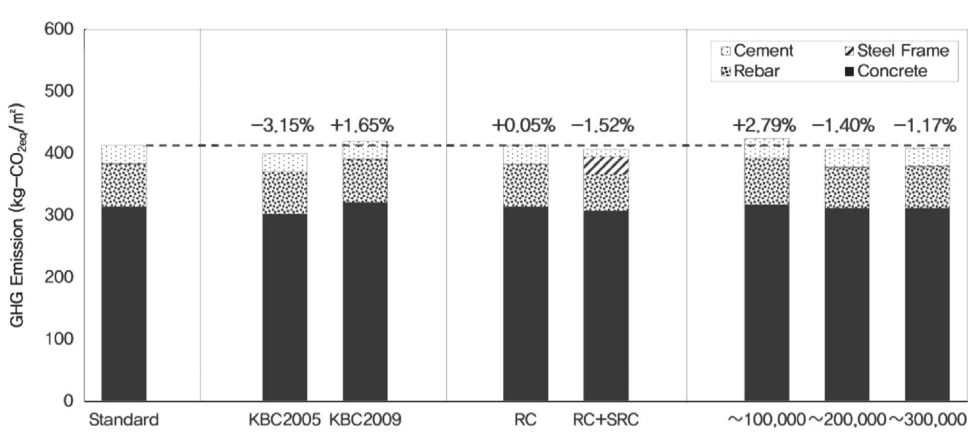



**Fig. 3.** Analysis of the GHG emissions of the building materials.

**Table 5**
Example of standard work code of building materials for evaluation.

| Pure resource code | Product name | Specification | Unit |
|---|---|---|---|
| 3011150520143288 | Ready-mixed concrete | Seoul, 19-45-15 | $m^3$ |
| 3011150520143289 | Ready-mixed concrete | Seoul, 20-35-08 | $m^3$ |
| 3011150520143290 | Ready-mixed concrete | Seoul, 25-18-08 | $m^3$ |
| 3011150520143291 | Ready-mixed concrete | Seoul, 25-18-10 | $m^3$ |
| 3011150520143292 | Ready-mixed concrete | Seoul, 25-18-12 | $m^3$ |
| 3010161920160898 | Bar steel for rebar concrete | Deformed bar (SD300), D10 | t |
| 3010161920160899 | Bar steel for reinforced concrete | Deformed bar (SD300), D13 | t |
| 3010161920160900 | Bar steel for reinforced concrete | Deformed bar (SD300), D16 | t |
| 3010150420288693 | Angles | Equal side, 25 × 25 × 3 mm | kg |
| 3010150420288694 | Angles | Equal side, 30 × 30 × 3 mm | kg |
| 3011160120142681 | Cement | Cement | kg |
| 3011160120144798 | Tile cement | Tile cement | kg |

**Table 6**
Analysis of building material input and GHG emission.

| Classification | Division | Building material input per unit area | | | | GHG emission per unit area((kg-$CO_{2eq}$/$m^2$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Concrete ($m^2/m^2$) | Rebar ($t/m^2$) | Sectional bar ($t/m^2$) | Cement ($kg/m^2$) | Concrete | Rebar | Sectional bar | Cement | Subtotal | Error (%) |
| Standard | Total Average | 0.91 | 0.09 | 0.00 | 31.30 | 313.36 | 68.85 | 0.94 | 29.54 | 412.70 | – |
| Completion Year | Before 2010 | 0.87 | 0.09 | 0.00 | 31.17 | 301.88 | 68.39 | 0.00 | 29.42 | 399.69 | −3.15 |
| | After 2010 | 0.93 | 0.09 | 0.00 | 30.19 | 320.78 | 68.30 | 1.94 | 28.50 | 419.51 | +1.65 |
| Structure | Apartment house with RC structure | 0.91 | 0.09 | 0.00 | 31.92 | 313.58 | 69.20 | 0.00 | 30.13 | 412.91 | +0.05 |
| | Apartment house with SRC structure | 0.89 | 0.08 | 0.07 | 13.16 | 307.08 | 58.94 | 28.00 | 12.43 | 406.44 | −1.52 |
| Total Floor Area | Under 100,000 $m^2$ | 0.92 | 0.10 | 0.00 | 33.66 | 316.78 | 75.67 | 0.00 | 31.77 | 424.22 | +2.79 |
| | Over 100,000 $m^2$ Under 200,000 $m^2$ | 0.90 | 0.09 | 0.00 | 30.47 | 311.70 | 65.34 | 1.10 | 28.76 | 406.90 | −1.40 |
| | Over 200,000 $m^2$ | 0.90 | 0.09 | 0.00 | 29.89 | 311.87 | 66.11 | 1.69 | 28.21 | 407.88 | −1.17 |

## 4. Results

### 4.1. GHG emissions assessment criteria in G-SEED

This study organized a GHG emission assessment criteria for input resources in buildings in terms of the materials and resource assessment for Korea's G-SEED, targeting apartment houses in connection with BEGAS. The aim of GHG emissions assessment in terms of the building input resource is motivated by the fact that $CO_{2eq}$ converts 6 types of GHGs ($CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$), defined in IPCC emitted by the material production, into $CO_2$ emissions using the GWP for all structures, including buildings and attached buildings [54]. In case of a reinforced concrete apartment house, the ready-mixed concrete, rebar, and cement were analyzed, and, in case of a steel frame or steel frame reinforced concrete building, were proposed calculating this after adding the sectional bars. In addition, GHG emissions of the main building materials per unit area were evaluated using the official coefficient of emission (Korea LCI DB [27], Korea National DB of MOLIT [28]), and rated into grade 1 or 2. For the preliminary certification, the design details, the calculation of the major materials and the GHG emission calculation report should be submitted. For certification, statements on the construction expense, the major materials application according to the construction expense (indicating information on the major materials application if a carbon footprint labeling certification product [29] is applied) and GHG emission calculation reports are critical documents for submission. Fig. 4 shows the assessment criteria of the GHG emissions of building materials in G-SEED (Plan). This enables researchers to quantitatively recognize GHG emissions due to the use of resources in the building by calculating GHG emissions resulting from the buildings' materials. By encouraging the application of building materials and technologies that reduce various kinds of GHG, this method is considered as effectively reducing the GHG emissions of building materials.

### 4.2. BEGAS to support the G-SEED

The evaluands of BEGAS were set to 4 types of building materials (ready-mix concrete, cement, bar steel, sectional steel for reinforced concrete) that could be easily applied at the assessment stages (preliminary certification, certification) of the Korean G-SEED. The scope of GHG was set to 6 types of GHG ($CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$) emissions set at IPCC, and expressed as carbon dioxide equivalent ($CO_{2eq}$) in consideration of the GWP for each gas [54]. The main databases of the BEGAS were Korea LCI DB [27], constructed by the Ministry of Knowledge and Economy and the Ministry of Environment in consideration of the environmental features of Korea, and the Korea National DB on environmental information concerning building materials [28], constructed by Ministry of Land, Infrastructure and Transport (MOLIT) in a GHG




**Fig. 4.** Configuration of BEGAS.

**Table 7**
Status of LCI database by building materials.

| Classification | Name | Basic unit | Unit | DB source | Remarks |
|---|---|---|---|---|---|
| Ready-mixed concrete | Ready-mixed concrete | 346.000 | kg-$CO_{2eq}$/$m^3$ | National LCI DB | – |
| | Ready-mixed concrete [Spec.: 25-24-150] | 835.000 | kg-$CO_{2eq}$/$m^3$ | Carbon labeling | Applicable for certification |
| | Ready-mixed concrete [Spec.: 25-21-150] | 201.000 | kg-$CO_{2eq}$/$m^3$ | Carbon labeling | |
| | Pre-cast concrete [MPS build-up girder] | 189.000 | kg-$CO_{2eq}$/$m^3$ | Carbon labeling | |
| Rebar | Steel-making at electric furnace—Rebar | 0.760 | kg-$CO_{2eq}$/kg | National LCI DB | – |
| Sectional bar | H sectional steel | 0.397 | kg-$CO_{2eq}$/kg | LCI DB of MOLIT | – |
| Cement | Cement | 0.944 | kg-$CO_{2eq}$/kg | National LCI DB | – |

basic unit of general building materials. If a Korea carbon footprint labeling product [29], designed by the Korea Environmental Industry & Technology Institute (KEITI) were used in the building at the time of completion and the building materials were disclosed, this information was applied to the GHG unit of the carbon footprint labeling. Table 7 shows the LCI database of the ready-mixed concrete, rebar, sectional bar and cement. The main function of the BEGAS developed in this study is the assessment of GHG. It was configured to have 2 simple screens of information input and results for an easy assessment of GHG emission of

| Green Building Certification Standard 2013 | | Apartment House |
|---|---|---|
| Area of Evaluation | 3 | Materials and Resources |
| Category of Evaluation | 3.4 | Utilization of Sustainable Resource |
| Criteria of Evaluation | 3.4.3 | GHG Emission of Building Input Resources |

■ Detailed Evaluation Standard

| | |
|---|---|
| Goal of Evaluation | Aims to reduce the GHG emission of building by recognizing the GHG due to use of resource in the building and encouraging application of various building materials and technologies reducing carbon with calculation of GHG emission emitted by the resource used for building. |
| Evaluation Method | Calculation of GHG Emission of Resource Used for Building and Evaluation Results |
| Score | 2 points (evaluation items) |
| Standard of Calculation | • Grade = (Weighted Value) × (Points) |

| Classification | Contents of Evaluation | Weighted Value |
|---|---|---|
| Grade 1 | If the result is less than 410㎏−$CO_2$/㎡ per unit ㎡ by evaluating the GHG emission for main materials used for the building with application of official coefficient of emission | 1.0 |
| Grade 2 | If the result is over 410㎏−$CO_2$/㎡ per unit ㎡ by evaluating the GHG emission for main materials used for the building with application of official coefficient of emission | 0.5 |

※Official coefficient of emission : Korea LCI/DB, LCI/DB of MOLIT
※Targets of Evaluation : total construction works including building and attached building
※Main Materials : targets on ready−mixed concrete, rebar(bar steel), cement for reinforced concrete apartment house and calculate with addition of sectional bar in case of steel frame or steel frame reinforced concrete
※GHG emission : $CO_{2eq}$ of 6 types of GHG defined in IPCC emitted by the material production, converted to $CO_2$ emission using the Global Warming Potential(GWP)
 * 6 types of greenhouse gas : $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$
※Main material input is based on the details of design and input from statements of work cost are used in principle according to details of construction cost
※If necessary, evaluation program (BEGAS) can be used according to government service
※Assessment results are submitted with calculation of total emission and emission per unit area(floor area)

■ Evaluation Reference and Documents for Submission

| | | |
|---|---|---|
| Reference | | − Building material Embodied Greenhouse gas Assessment System : http://www.SUSB−BEGAS.co.kr<br>− National LCI database information network(http://www.edp.or.kr)<br>− GHG labelling of product by the Ministry of Environment (http://www.edp.or.kr) |
| Documents for Submission | Preliminary Certification | − Details of Design and Details of Calculation of Main Materials per Details of Design<br>− Carbon Emission Calculation Report |
| | Certification | − Statement of construction work and statements of main material application according to statement of statement of construction work(indicate in the statements of main material application if carbon labelling product is applied)<br>− GHG emission calculation report |

**Fig. 5.** Assessment criteria of the life cycle carbon emissions of the building input resources in G-SEED (plan).

building materials. It can be evaluated by separating the preliminary certification from the certification, according to the progress of G-SEED, and then further distinguishing between the manual input for the quantities of main building materials emitting GHG and the automated input. Fig. 5 shows the configuration of BEGAS developed by this study.

#### 4.2.1. Preliminary certification

For a preliminary certification, the basic building informations were noted, using either the automated or manual input for the building materials, and determined the assessment results using the assessment button. At this time, for the manual input, the user directly enters and evaluates the quantities of 4 types of building materials. For the automated input, details of the quantity of building materials are summarized according to the designated input format, a file in Excel form is imported and evaluated.

The results of the preliminary certification consist of basic information about the building (assessment information, building information), results of GHG emissions, a GHG emissions assessment grade for the building's input resources, and the logistics of the GHG emissions calculations for each of the building materials. This analysis was configured to enable a relative comparison with the standard GHG emissions of apartment house building materials. In addition, the results can be utilized as the GHG emission assessment results of building input resources through output, and its details can be downloaded in Excel form, utilized as the documentary evidence of GHG.

#### 4.2.2. Certification

The certification was configured in the same form as the preliminary certification. The building materials, for which the KEITI carbon footprint labeling was obtained, can be entered and applied here in addition to the general building materials. These are separated into manual input and automated input, depending on the input method. For the input method, bills of quantities can be edited in the input format, and imported into an Excel file for assessment.

The results of the certification are configured just as with the preliminary certification; however, the results of the building materials that obtained carbon labeling appear on the bottom. These can be printed or downloaded in an Excel file using the system same as the preliminary certification, and can be utilized as the results of GHG emissions of the building input resource.

## 5. Discussion

In this chapter, the building material GHG assessment criteria and level of BEGAS developed in this study were analyzed. Based on the application level in the certification system for building materials GHG emission assessment analyzed in "2. Literature Review", limitations and future directivity of this study were deduced through comparison of GHG emission assessment scope to be applied to G-SEED of Korea with other certification systems.

In this study, Building materials Embodied GHG Assessment Criteria and System (BEGAS) suitable for construction environment and level of Korea were developed in order to assess GHG emission of building materials and to reflect it on the G-SEED being newly amended in Korea. Especially, building materials GHG assessment criteria developed in this study have limited scope of assessment and evaluands in comparison to other existing certification systems (LEED, BREEAM, CASBEE, etc.), but the meaning of building materials GHG emission assessment is in that it is newly reflected in the certification system according to stage 1.

BEGAS assesses GHG emission of 4 building materials that agree with the conditions of the Korean construction industry based on 7 building materials responsible for over 90% of total embodied GHG emission by building materials used in buildings. This system does not consider life cycle of buildings as in the certification criteria, but it supports convenient assessment of GHG emission by developing an auto quantity input technique not used in other systems. In addition, development of a system considering the Korean construction industry is meaningful based on the fact that other certification systems recommend the use of programs developed in a nearby (or similar) nation for consideration of regional environment during assessment of GHG emission. This study is an early stage study that applies building materials GHG emission assessment for the first time. While the level of application is relatively limited compared to LEED of the US and BREEAM of the UK, it is expected to develop into an assessment criterion for assessing life cycle of buildings except for the stage of use based on 6 major environmental impact categories similar to the method of LEED. Existing GHG emission assessment systems such as Athena EcoCalculator and Envest2 can be linked with G-SEED, and scores can be granted according to GHG reduction compared to specialization of environmental impact in the standard building with the same purpose, region and size. In addition, it can further be improved as a LCA on buildings including the stage of use, based on more than 6 environmental impact categories as in BREEAM of the UK. Also, according to the latest trend of increase in BIM orders that include diverse information about buildings intended to enhance efficiency of building design and construction, application of systems that can be used with BIM (IMPACT, etc.) can be taken into consideration in the future. On one hand, in order to improve the level of GHG emission assessment as described above, it would be necessary to continuously conduct studies on construction of Korean LCI DB and connection of building LCA with the certification systems.

## 6. Conclusion

This study aims to develop a Building materials Embodied GHG Assessment Criteria and System (BEGAS) in the newly revised Korea Green Building Certification System (G-SEED). The following conclusions were derived from this study:

1. Reflection methods on the building materials GHG assessment in the G-SEED were elicited through the review of a relationship between the green building certification system and GHG assessment system.
2. The major building materials, including ready-mixed concrete, rebar, sectional bar and cement, were selected by analysis on the bills of quantities for buildings, focusing on GHG emissions and reviews from the G-SEED Technical Committee.
3. The standard GHG emissions of the main building materials were identified by analyzing the bills of quantities for 60 types of apartment houses constructed in Korea for the establishment of a standard building certification criteria and BEGAS. In addition, an automated quantity input technique was established using the standard work codes of PPS as a medium.
4. The GHG emissions assessment criteria (plan) of the building materials was configured in the areas of materials and resource assessment in Korean G-SEED for apartment houses, in connection with BEGAS.
5. A web based BEGAS was developed for easy application in Korean G-SEED. This allows for the calculation of GHG emissions emitted by the resources used in buildings, resulting in reduction of GHG emissions and encouraging the application of building materials and technologies with reduced GHG.

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